

3.45 in file 100-1700
Copies in file 100-1700

L E A P

Lockheed

Electra

Action

Program

September 15, 1960

LEAP

LOCKHEED ELECTRA ACTION PROGRAM

Table of Contents

<u>Title</u>	<u>Page</u>
INTRODUCTION	1
Purpose and Scope of Publication	1
Cause of Electra Accidents (Buffalo, Texas and Tell City, Indiana)	1
Investigation	3
FAA Activity	3
Lockheed Activity	4
Conclusions	5
AIRPLANE CHANGES	5
Wing	5
General	5
Outer Surfaces	6
Upper Surface	6
Lower Surface	7
Ribs	7
General	7
Truss Rib Changes	8
Tank Rib Changes - Wing Stations 155 and 221	8
Front Beam	8
Main Landing Gear Rib - Foot Reinforcement (S/B 503)	9
Powerplant	20
General	20
QEC	20
Engine Mounts	20
Engine and Propeller	21
Diagonal "V" Braces	22
Nose Cowl	22
Top Cowl Panel	23
Side Cowl Panels	23
Bottom Cowl Panel	24
Miscellaneous QEC Changes	24
Nacelle	25
Fittings	25
Longerons	25
Miscellaneous Nacelle Changes	26

List of Illustrations

Electras in Modification Jigs	10
Wing Modification	13
Wing Rib Modification	16
QEC Modification	27
Modified QEC (Mock-up)	30
QEC Cowl Modification	31
Nacelle Modification	32

LOCKHEED ELECTRA ACTION PROGRAM (LEAP)

1. INTRODUCTION

A. Purpose and Scope of Publication.

The prime purpose of this publication is to present, in a comprehensive manner, Lockheed's program to enable lifting the current restricted speed placard from the Electra.

Details concerning modifications and installation of components have been purposely omitted; however, the material presented will provide the reader with enough information in the way of reasons why, what is being done, and what can be expected to enable a better understanding of the term "LEAP".

B. Cause of Electra Accidents (Buffalo, Texas and Tell City, Indiana)

As previously announced, the cause of the Electra accidents is as follows:

"Heretofore unsuspected propeller gyroscopic forces operating in a damaged powerplant installation and in the presence of suitable excitation coupled with wing bending frequencies to overload the wing to the point of failure".

Logically from this reply we might ask, why "unsuspected?" The answer is that previous studies of gyroscopic-aerodynamic instabilities of aircraft are few in number and our previous studies and tests had indicated that no practical flutter problem existed in the Electra. Further research and investigation brought forth the nature of these "gyroscopic forces".

The propeller acts like a gyroscope because of the large rotating mass. The axis of the propeller moves (precesses) in a direction at 90 degrees

"Whirl mode" occurs only when it is excited (nudged) by some outside force. In the absence of serious damage it is immediately damped out, thus damage in the powerplant installation area becomes an important factor.

First, the greater flexibility of a damaged installation can allow the "whirl mode" more freedom and it may become violent. In a "healthy" nacelle, stiffness is sufficient to damp out the "whirl mode" immediately, but in a damaged one this characteristic may be altered.

Third, and most important: with a changing "spring constant", frequency varies inversely with amplitude. The greater amplitude of the whirl

2

mode in damaged and over-flexible structure reduces its frequency from its natural value in "healthy" structure, which is safely above the natural frequencies of the wing, to lower values approaching those wing frequencies.

The natural "whirl mode" frequency in an undamaged installation is about 6 cycles per second (cps). The wing in torsion is about 3-1/2 cps, and in bending 2 cps, varying slightly with fuel load. At 3 "whirl mode" cycles per second the propeller would "drive" the wing in a 3-cps torsional oscillation and in repeated up and down bending, at 3 cps -- and these wing oscillations would in turn reinforce and perpetuate the whirl mode. That is, the three oscillations would be "coupled" at the same frequency. The effect of this "couple" could then overload the Electra wing to the point of failure.

NOTE: Our tests indicate this coupling, even under above conditions, would be damped out at airspeeds of 225 knots (IAS) or less.

C. Investigation.

(1) FAA Activity

FAA directives after the accidents resulted in the following action:

- (a) Indicated speed restricted to 225 knots for the Electra.
- (b) Deactivation of the automatic pilot.
- (c) Lockheed to initiate and be responsible for LEAP.

Fulfilling the requirements of item (c) required, among many other research programs, a complete reaudit of all the mathematical calculations used in developing and designing the Electra; a flight

test program conducted under the most severe conditions of turbulence; static testing and wind tunnel experiments in excess of those originally accomplished for the Electra or other commercial aircraft.

(2) Lockheed Activity

The following lists briefly Lockheed's important sources of information during the research phase of LEAP.

- (a) Careful analysis of the wreckage.
- (b) Electra airplane 1001, the Lockheed test airplane, very heavily instrumented, notably in its flights through the permanent turbulence known as the "Sierra Wave".
- (c) Electra airplane 1077, the closest mate to NWA's airplane 1057 which crashed. Airplane 1077 has furnished data of three kinds: through an extremely minute structural and systems inspection; through re-determination of natural structural oscillatory frequencies, confirming on a production airplane (which has seen airline service) the values originally determined on airplane 1001; and through re-determination of structural stiffness in undamaged condition and, especially other stiffness features associated with simulated failures of powerplant installation elements.
- (d) Electronic computers, taking data from airplanes 1001 and 1077, achieving solutions to problems of dynamics involving as many as 59 simultaneous equations (network analyzers independently cross-checked by digital computers).

- (e) The wind tunnel, progressively refining and verifying the computing machine results.
 - (f) The field inspection of all Electras in service.
 - (g) The 'round the clock, seven day a week contribution of some 250 engineers assigned full time to the investigation.
- (3) Conclusions. .

Airplane changes will be made for two reasons. One, to prohibit the development of an undamped whirl mode oscillation under possible failure conditions and two, to incorporate into the wing design the new dynamic response data generated during the investigation.

The powerplant installation will be changed to provide redundancy in the engine mounting system. New auxiliary mounts at the top and bottom of the gear box and one at the rear of the engine will be added. QEC and nacelle structure will be stiffened by the use of more direct load paths and strengthened longerons and fittings.

All four QEC's will receive the same changes.

2. AIRPLANE CHANGES (See Figure 1)

A. Wing (See Figure 2)

(1) General

Design standards and regulations have, in the past, considered the effects of high rates of loading on the amplification of wing bending moments. During its design, the Electra was shown by analysis to have bending amplifications very comparable to past piston air-

planes. This fact was confirmed by the original flight tests and reaffirmed by the current flight tests. The more recent tests have shown, however, that consideration of bending amplification in turbulence is not sufficient in itself to guarantee strength compatible with past piston airplanes since significant differences in wing torsion can exist. The biggest contribution to these higher torsions results from the outboard nacelle dynamic response in the first bending mode. Due to this effect, increases in wing torsional strength will be accomplished in conjunction with wing modifications necessary on the basis of weight increase resulting from QEC and nacelle rework. Even though the original analysis of the wing was based on acceptable and time proven concepts, Lockheed is increasing wing strength as further insurance. The end result will be a modified wing with improved strength capabilities.

(2) Outer Surfaces

(a) Upper Surface

Upper wing panel number 2, left and right sides, will be replaced. The geometry of the new panel is similar to existing panels. The new panel will provide increased area since riser height and thickness, and skin thickness is increased.

Areas adjacent to the access doors in panel number 3 are strengthened by adding internal reinforcements.

Strap reinforcements are added to the risers of panel number 4 from W.S. 275 to 329 on airplanes 1001-1034.

(b) Lower Surface

Lower wing panels numbers 1, 2, and 3 left and right will be replaced. The geometry of the new panels is similar to existing panels. Riser height and thickness and skin thickness have been increased.

To reduce shear stresses and increase the torsional strength required between nacelles, an external doubler is added for all airplanes on the lower surfaces (left and right) from W.S. 221 to W.S. 360 extending from the forward edge of the number 4 panel to the rear beam. In addition, airplanes 1001 - 1014 will include a doubler (and straps on risers of existing panels) from W.S. 360 to W.S. 516 extending from the forward edge of the number 4 panel to the rear beam.

(3) Ribs (See Figure 3)

(a) General

The wing ribs are being improved even though previous wing rib damage was incidental to surrounding structural failure when the airplane was involved in hard or crash landings. Actually the wing has good strength margins under any operating condition with any panel completely disconnected from more than one rib, a condition very much more extreme than reported by field service inspection. In keeping with the "wing strength insurance policy", rib changes will make rib deflection characteristics consistent with wing box distortions.

(b) Truss Rib Changes

Nineteen ribs between W.S. 65 and W.S. 397 will have diagonal member changes. Three new extrusions are required for this modification. The diagonal extrusion will be similar to the present diagonal but of a heavier cross section. A new Z-extrusion will be used for doublers added between the new diagonals and the rib caps. Some caps will be replaced with new section extrusions where the length of the Z-member becomes too long to be practical. The outboard nacelle ribs at W.S. 346 and W.S. 380 are strengthened by adding shear webs to the forward rib portions in lieu of bracing.

Approximately 80 percent of the "H"-clip to rib cap attachments from W.S. 65 to W.S. 397 will be reworked to replace the two rivets nearest the skin with steel Hi-Lok fasteners.

(c) Tank Rib Changes - Wing Stations 155 and 221

All posts at tank ribs are replaced with heavier members. The forward portions of the upper rib caps will be spliced to accommodate the new upper panel installation.

(4) Front Beam

The wing modifications required to meet the new gust load requirements affect the front beam. This requires the addition of flat aluminum doublers to the forward face of the front beam web at two locations, between the two nacelles and between the inboard nacelle and the fuselage. Web stiffeners and functional installations must be removed to add these doublers.

NOTE: Removed web stiffeners will be reused.

For airplanes 1001 - 1034, the doublers will be installed from W.S. 65 to W.S. 162 and W.S. 214 to W.S. 293.

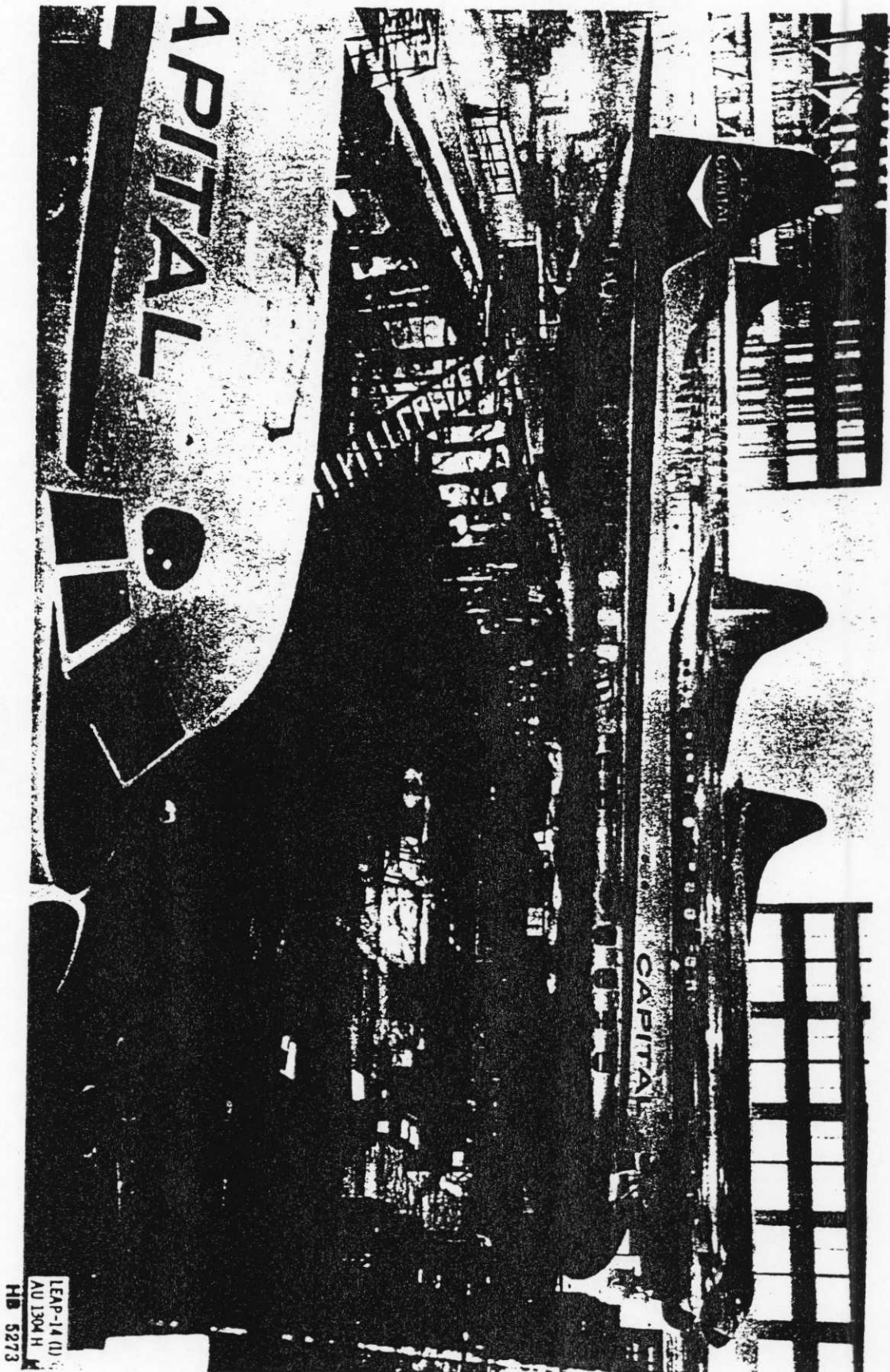
For airplanes 1035 and up and 2001 and up, the doublers will be installed from W.S. 65 to W.S. 101 and W.S. 214 to W.S. 275.

The result of the beam modification will be increased torsional shear strength.

(5) Main Landing Gear Rib - Foot Reinforcement (S/B 503)

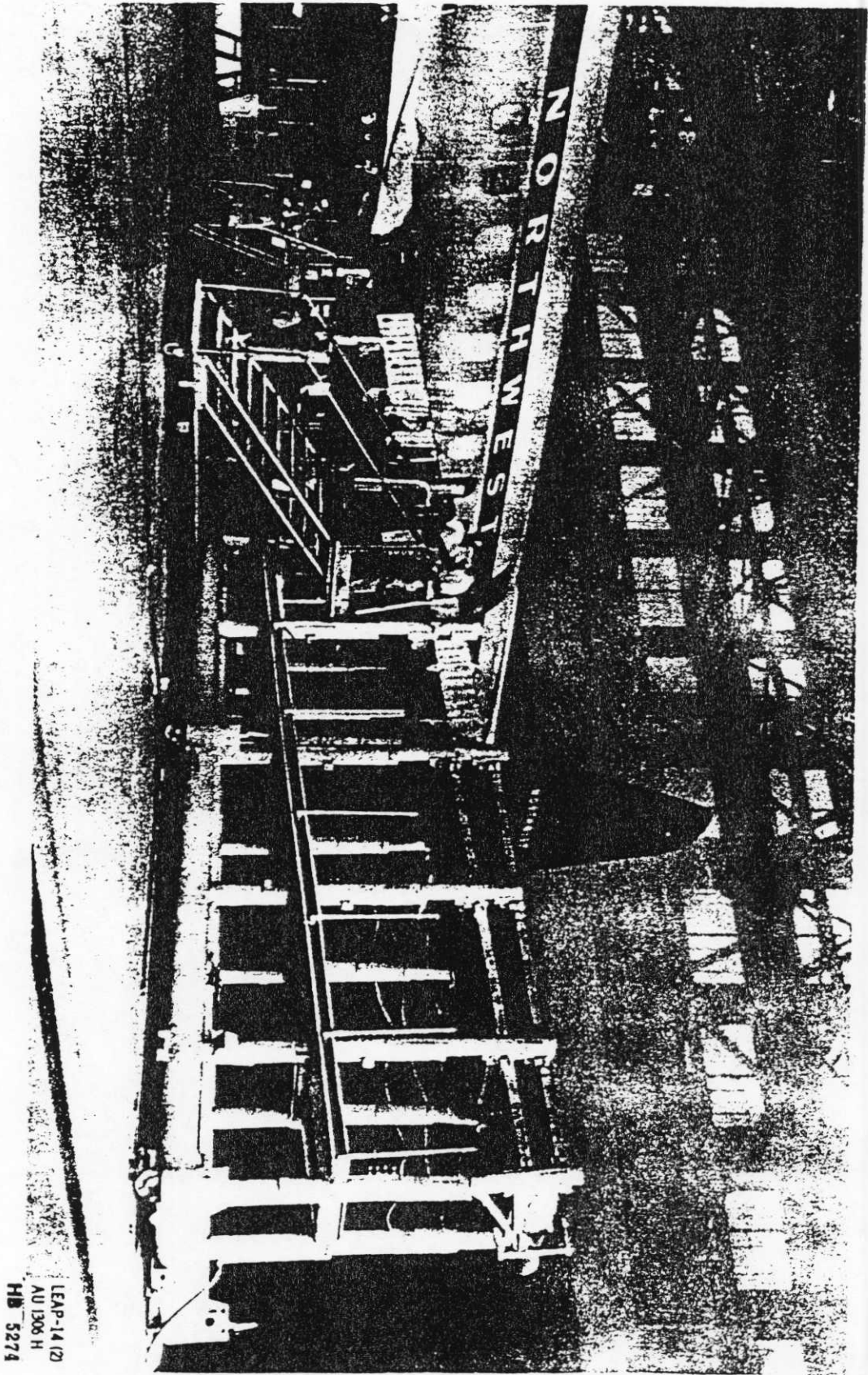
The rework of the main landing gear ribs has been defined by LAC Engineering as a mandatory change to be accomplished prior to or concurrent with Project LEAP but which is not necessary to lift the speed restriction placard as flight loads are not involved. Changes of this type have separate Service Bulletin identification.

Two new extrusions will be used for this change. Reinforcing clips, made from the new extrusions, will be added on the top and bottom ribs. Clips will be added to those tabs near the landing gear trunnion. Approximately 6 tabs on the bottom of each rib and 12 tabs on the top of each rib are affected.



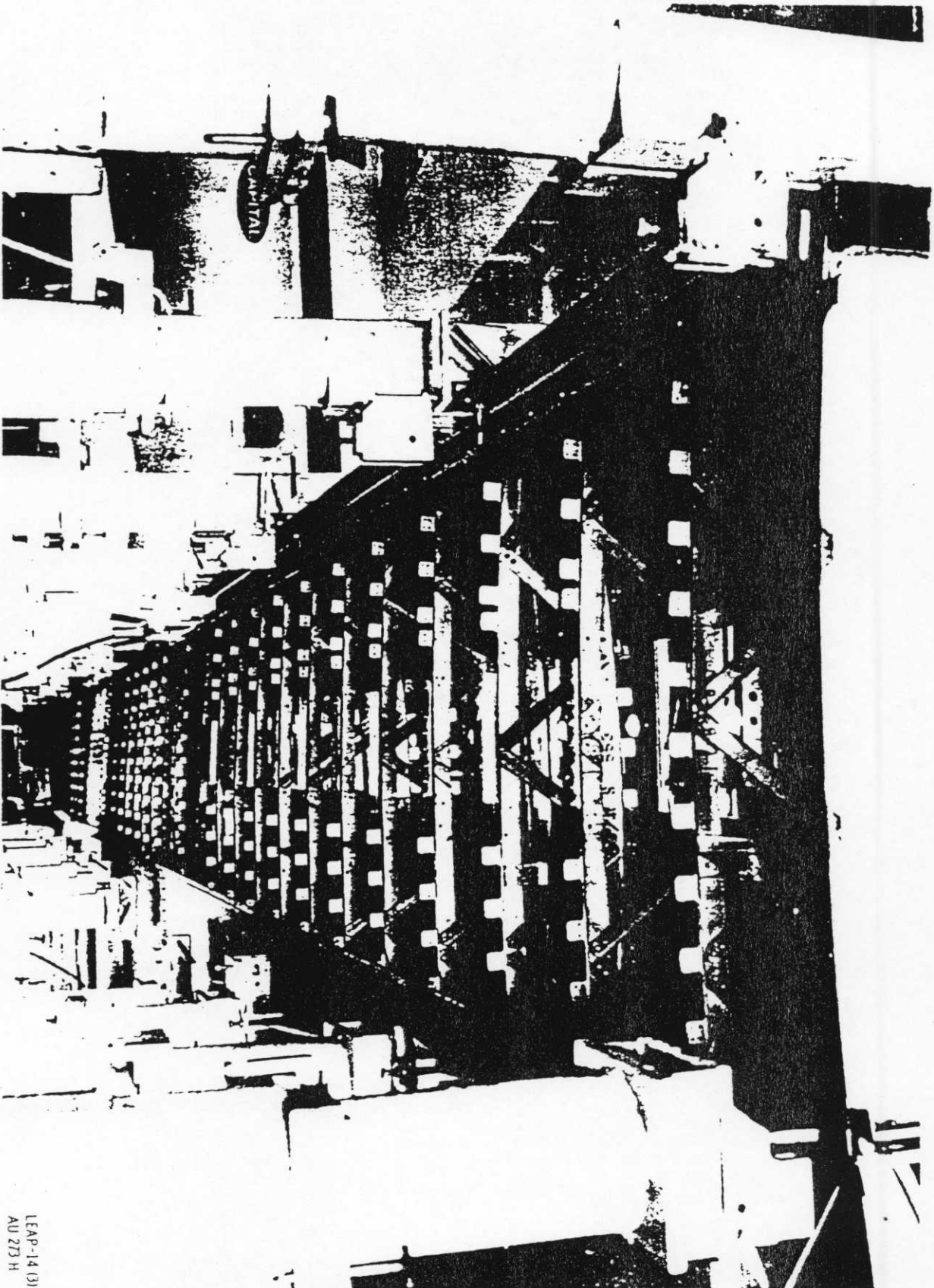
Electras in Modification Jigs
Figure 1 (Sheet 1)

LEAP-1A (1)
AU 1304 H
HB 5273



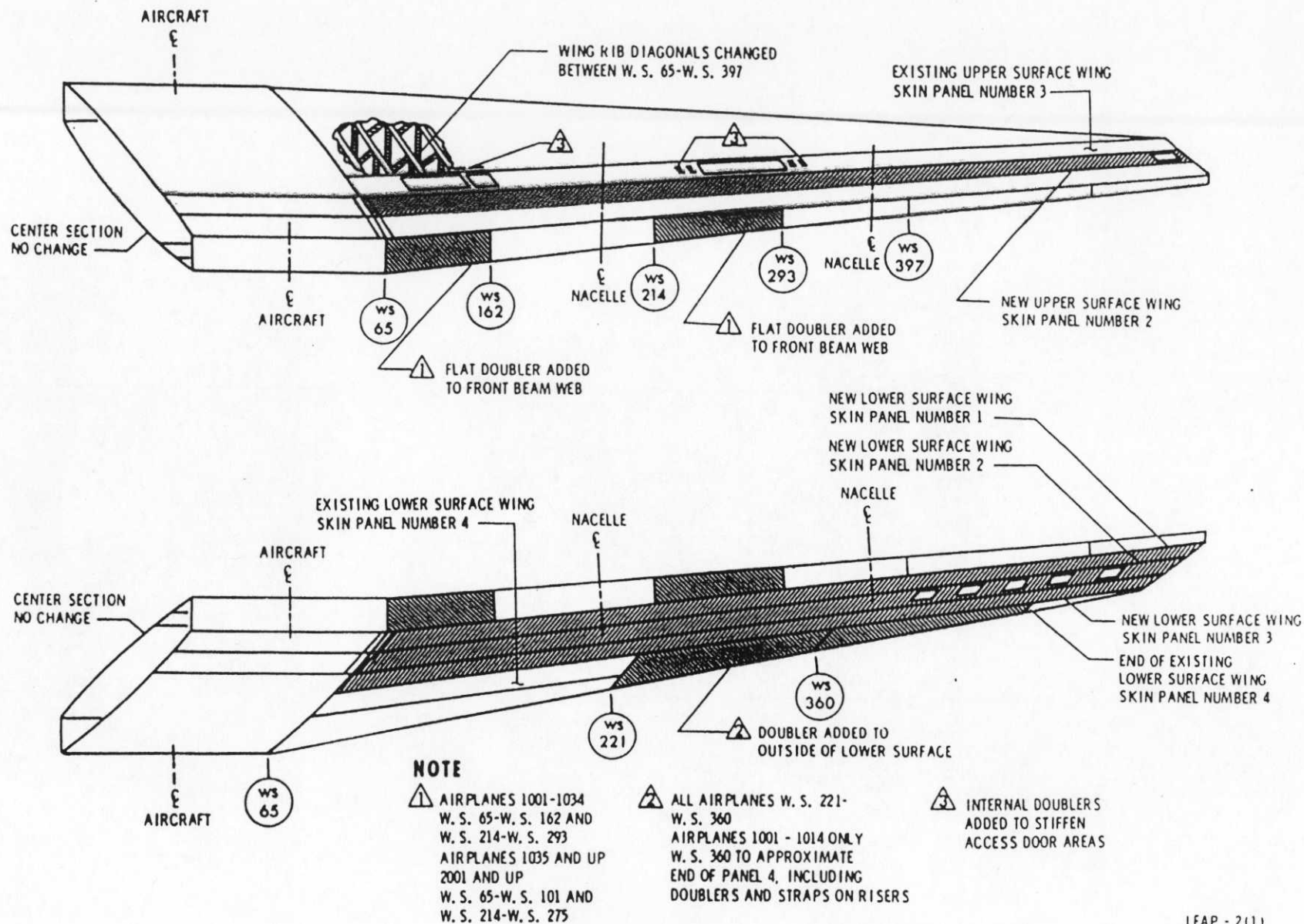
LEAP-14 (2)
AU 1306 H
HB 5274

Electrics in Modification Jigs
Figure 1 (Sheet 2)



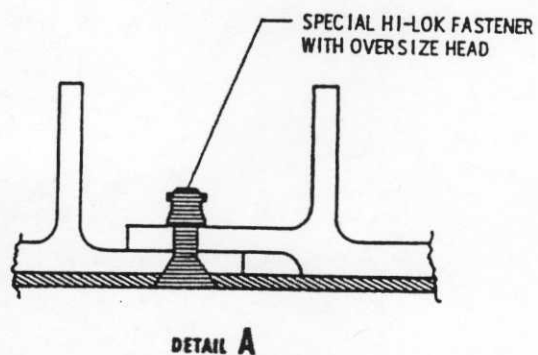
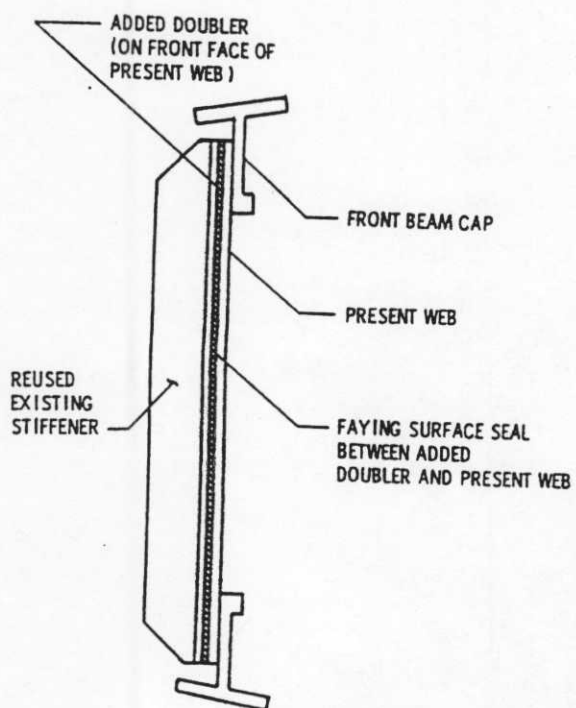
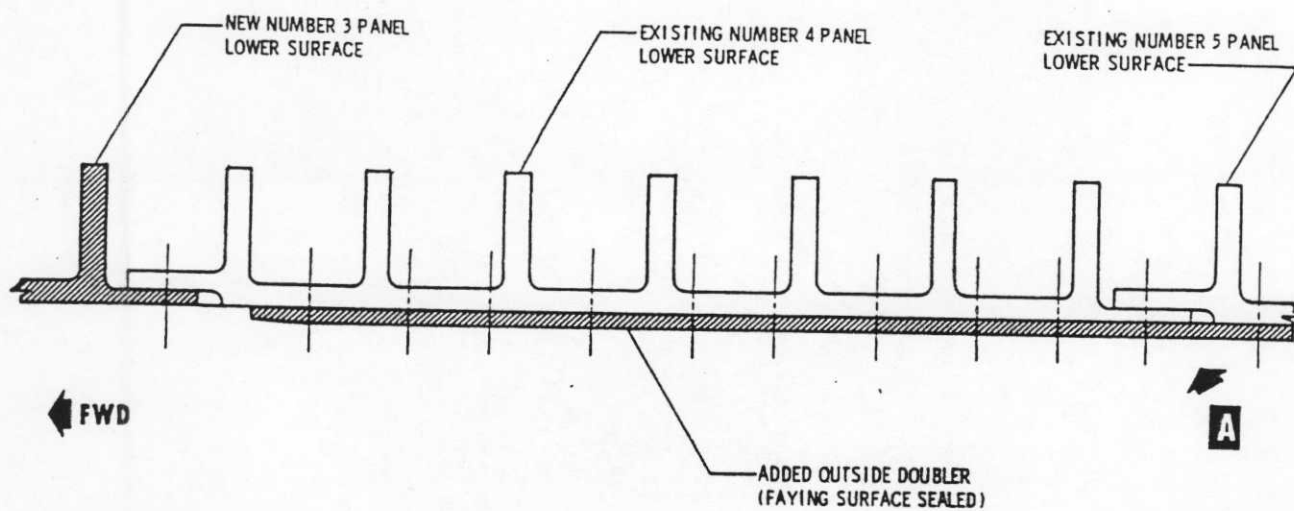
Electras in Modification Jigs
Figure 1 (Sheet 3)

LEAP-14 (3)
AU 273 H
HB 5275



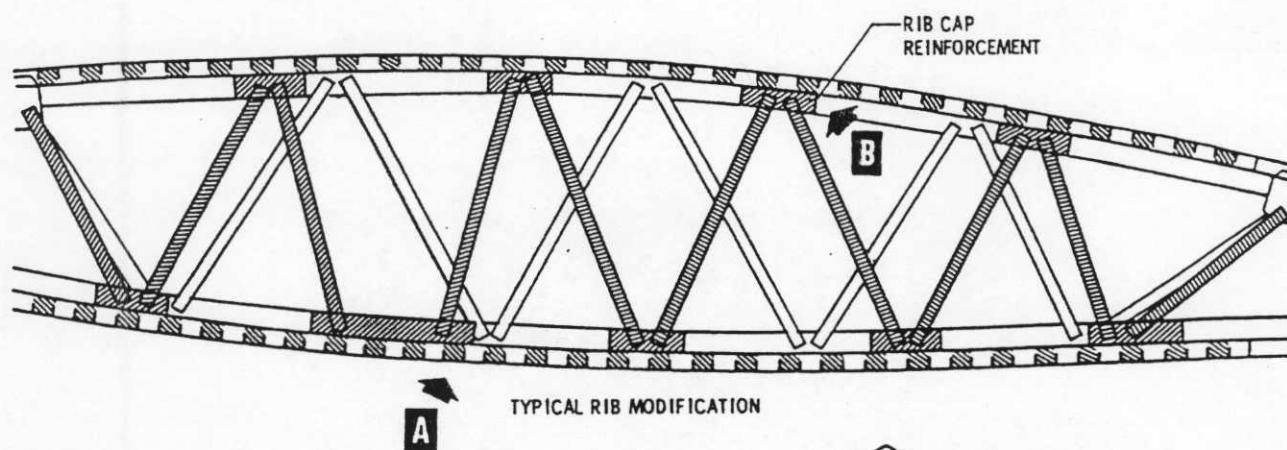
LEAP - 211)
HB 5276

Wing Modification
Figure 2 (Sheet 1)

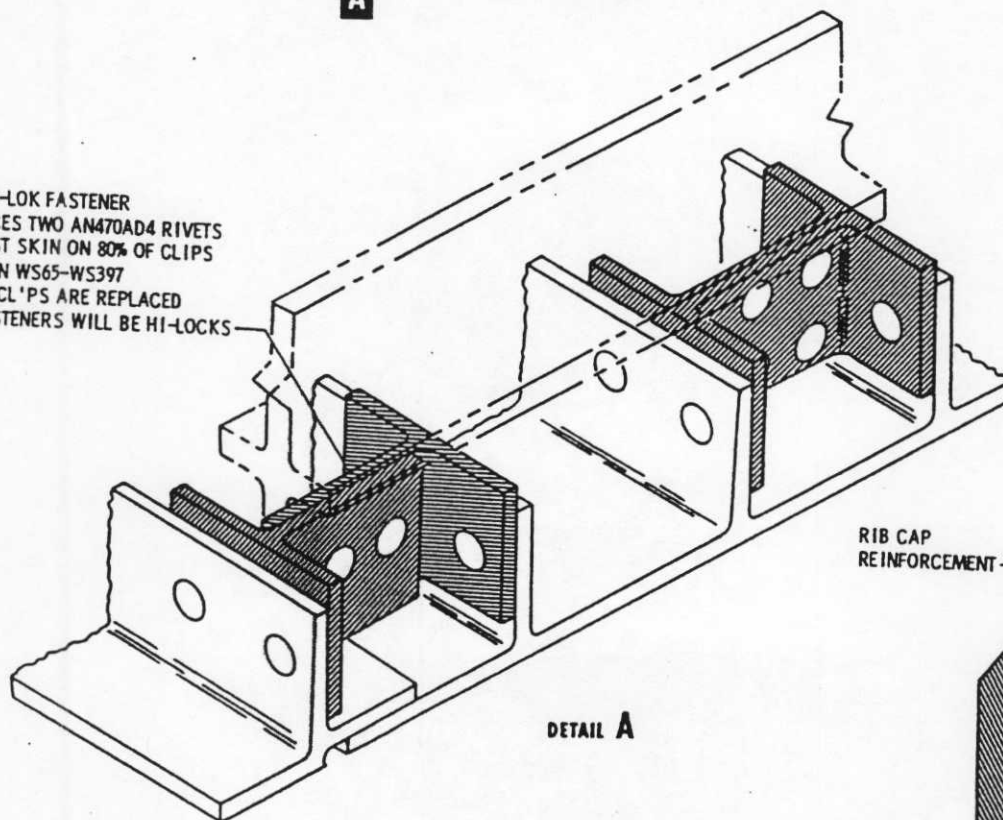


LEAP -2 (2)

Wing Modification
Figure 2 (Sheet 2)

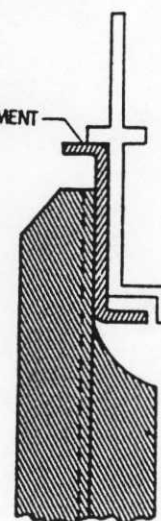


5/32 HI-LOK FASTENER
REPLACES TWO AN470AD4 RIVETS
NEAREST SKIN ON 80% OF CLIPS
BETWEEN WS65-WS397
WHERE CL'PS ARE REPLACED
ALL FASTENERS WILL BE HI-LOCKS



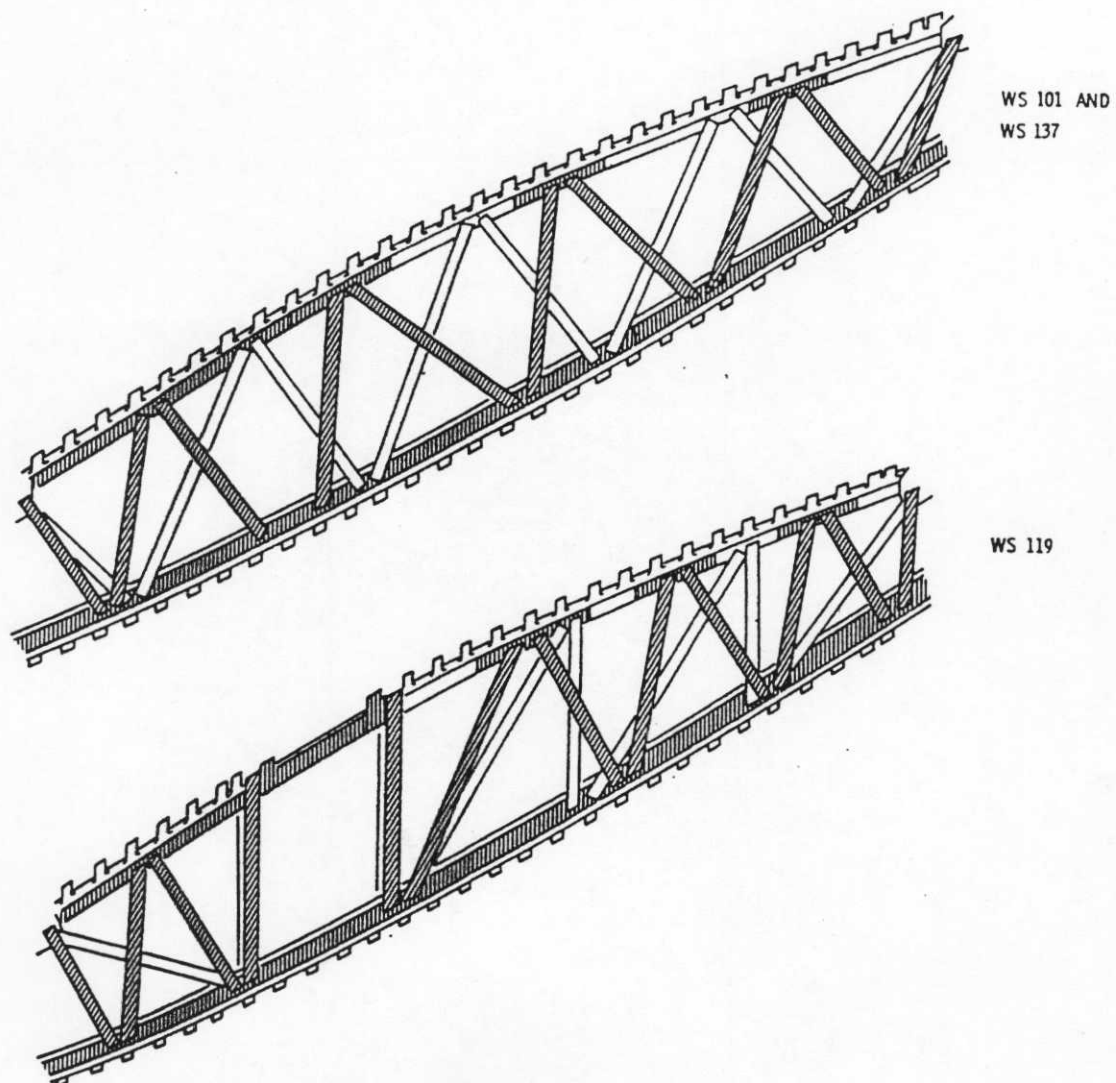
DETAIL A

RIB CAP
REINFORCEMENT



DETAIL B

LEAP 2 (3)



NOTE

— PRESENT RIB STRUCTURE

▨ MODIFIED RIB STRUCTURE

NO CHANGES, EXCEPT FOR RIB CAP TAB CHANGES FOR ATTACHMENT TO
NEW NUMBER 3 UPPER PANEL., ON RIBS AT FOLLOWING WING STATIONS:

W. S. 414, 431, 448, 465, 482, 499, 516, 533, 550, 567

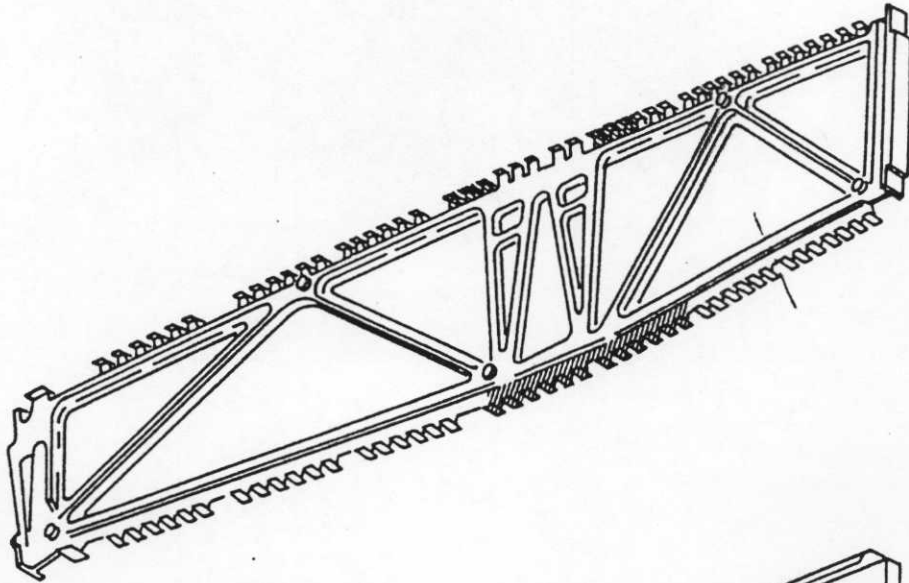
NO CHANGES TO RIBS OF WING CENTER SECTION

LEAP-1(1)

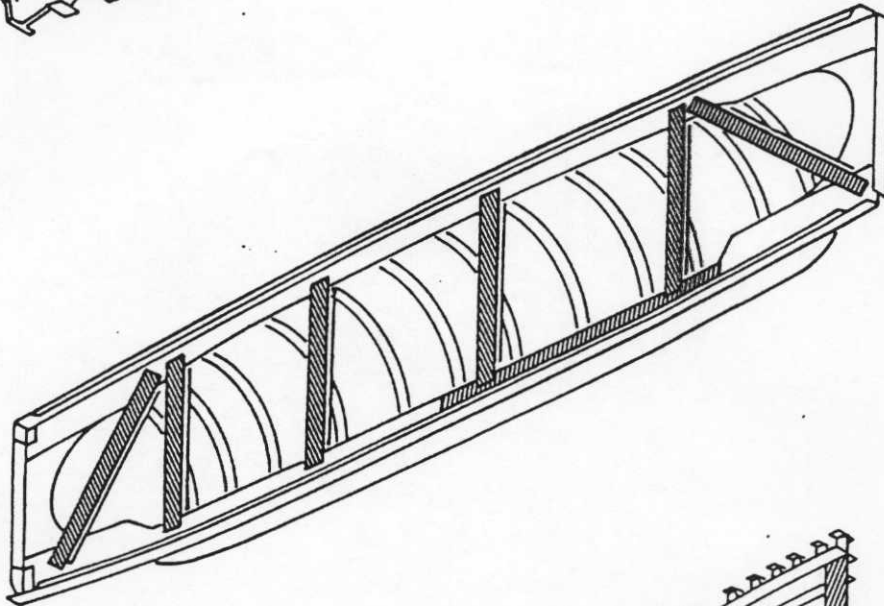
Wing Rib Modification
Figure 3 (Sheet 2)

LEAP-1(2)

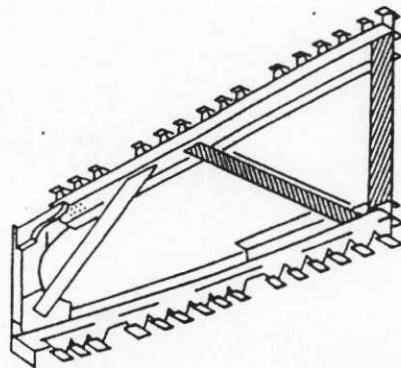
WS 167 AND WS 209
MAIN LANDING GEAR
RIBS SB 503



WS 155 AND WS 221
TANK RIBS

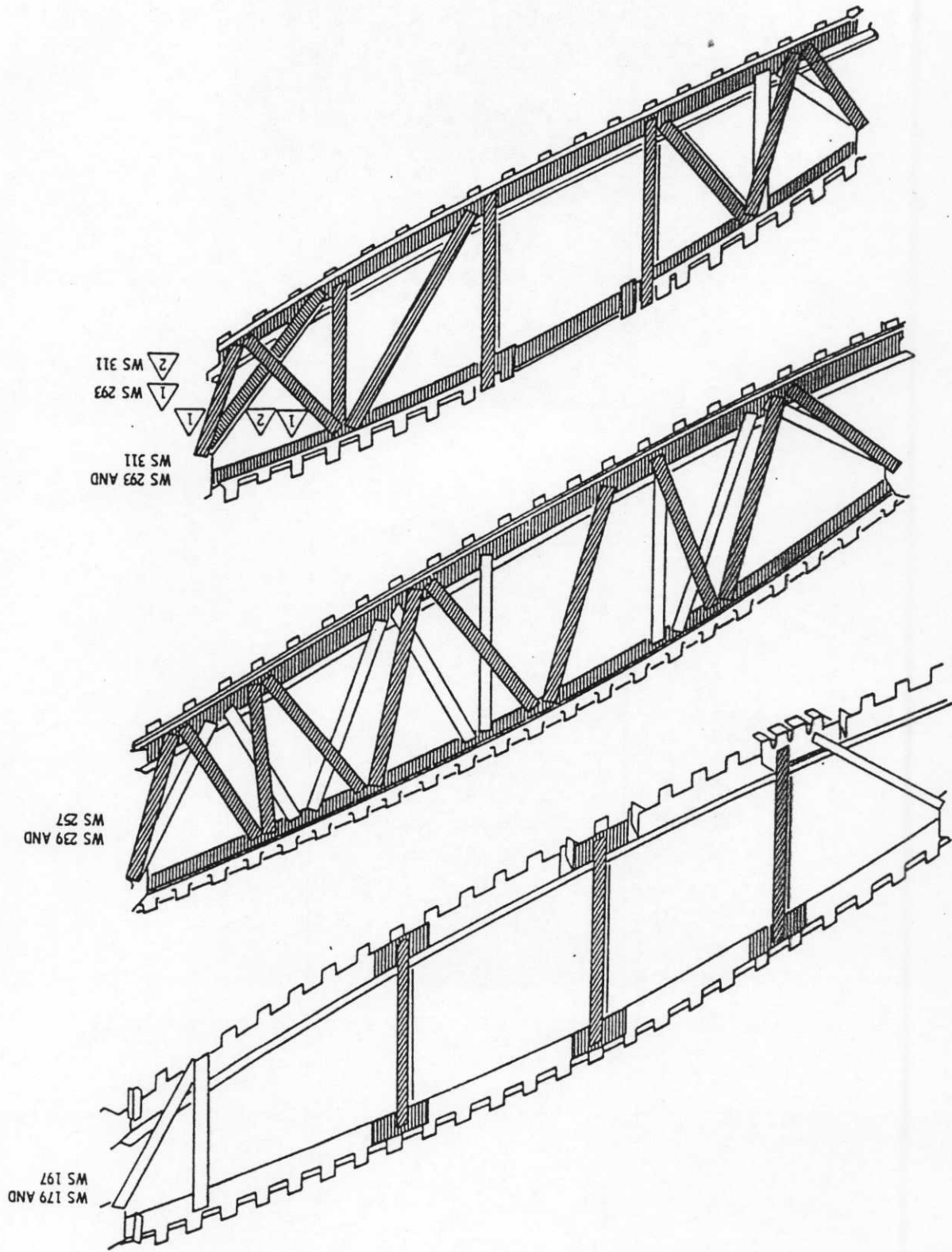


WS 143



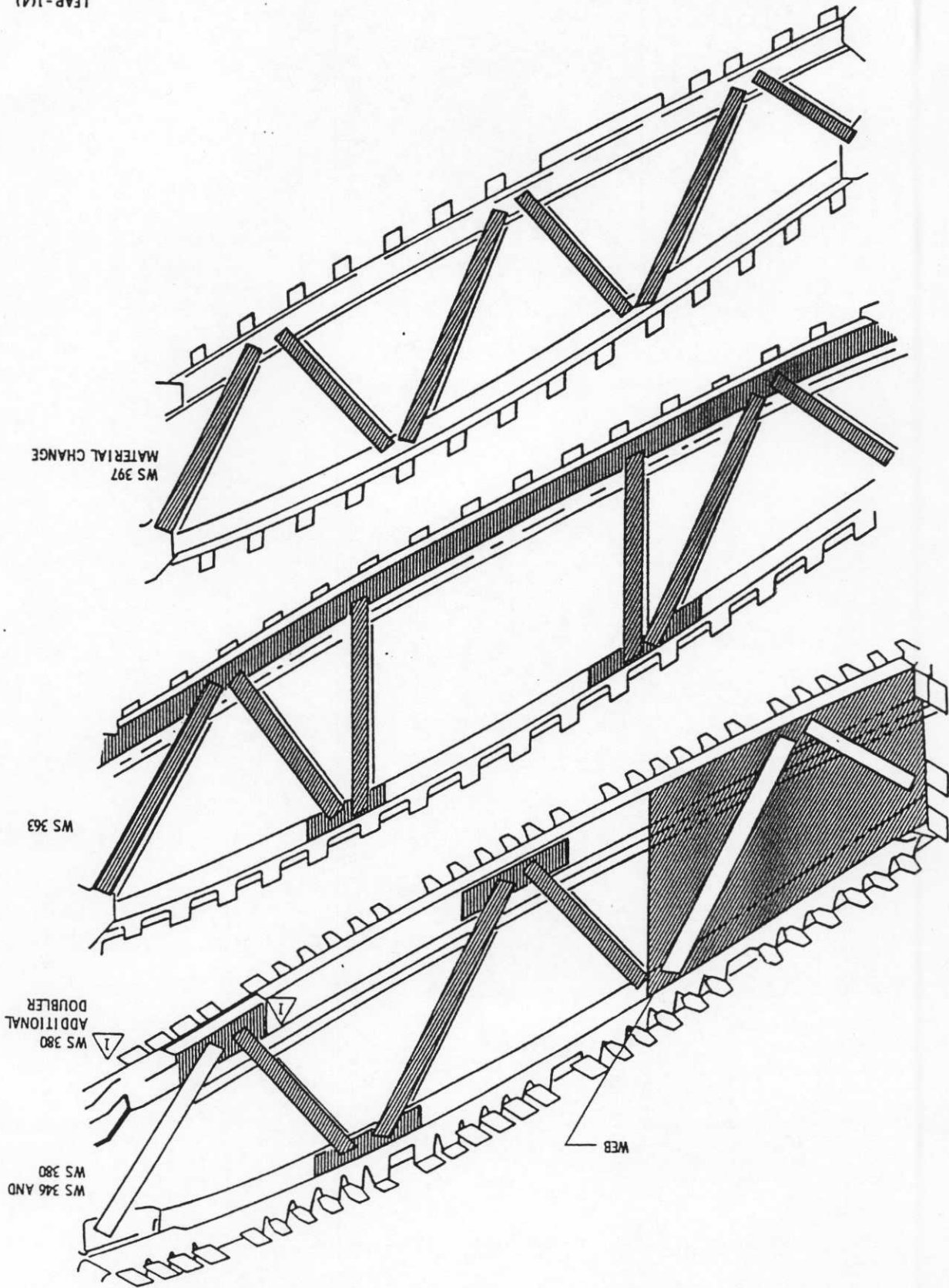
Wing Rib Modification
Figure 3 (Sheet 3)

LEAP-1(3)



Wing Rib Modification
Figure 3 (Sheet 4)

LEAP-114)



B. Powerplant

(1) General

The engine mounting system is made "fail safe" by the addition of four auxiliary engine mounts. Three mounts, two at the top and one at the bottom, are added to support the engine gear box. The two existing gear box side mounts are stiffened. A mount is added on the left side of the engine below the existing engine rear mount at the top of the engine, which remains unchanged. The QEC structure is stiffened by replacing the single diagonal brace on each side of the QEC with a "V" brace and by changes to the nose, top, bottom, and side cowls. No changes to the basic engine structure are required. The nacelle structure aft of the QEC is stiffened primarily by changes to the longerons and fittings that carry the loads between the QEC and the wing.

Changes are required to both inboard and outboard nacelles because of the added weight of the modified QEC's. The outboard nacelle is also affected by the dynamic behavior of the powerplant installation when the airplane penetrates a sharp-edged gust. For this reason the changes to nacelle structure are primarily in the outboard nacelles. However, identical changes are made to all four QEC's to maintain QEC interchangeability.

(2) QEC (See Figures 4, 5, and 6)

(a) Engine Mounts

The engine suspension arrangement is modified by changes to the existing engine mounts and by the addition of auxiliary

engine mounts. The original engine suspension consisted of two main mounts, one on each side of the engine gear box, and a rear mount supporting the engine at the top of the forward end of the hot section. The core material of the two existing forward mounts is changed to increase the fore and aft stiffness of these mounts 1.7 times. The metallic portion of these mounts is unchanged.

Three auxiliary mounts are added to support the gear box, two at the top and one at the bottom. Since interference prevented the installation of a single top mount at the centerline, two tandem mounts that straddle the centerline connect the gear box to the nose cowl through a "whiffle-tree" linkage. A rigging link is provided to lock pivoting while adjusting the two mount arms to remove preloading. The bottom mount is adjusted by means of shims.

The existing rear mount is unchanged, although the supporting structure is changed. An auxiliary mount is added on the left side of the engine below the existing top rear mount to restrain lateral movement of the rear of the engine. This side rear mount is attached to the engine by a lateral arm supported by an upper diagonal brace and an aft diagonal link.

(b) Engine and Propeller

The changes to the engine and propeller are confined to minor modifications to accommodate the new mounting configuration. The gear box is modified to provide mounting brackets for the additional two upper and one lower mounts. No modification is necessary to accommodate the added rear mount.

(c) Diagonal "V" Braces.

The bracing on each side of the QEC is modified by replacing the existing single brace with a "V" brace. The one-piece V-shaped brace consists of two diagonal tapered steel tubes, similar to the existing single diagonal. Three forged steel fittings are flash welded to the tubing at the forward point and the upper and lower aft ends. The forward fitting is bolted to the nose cowl above the side mounts. The aft fittings are bolted to the nacelle structure in a manner similar to the existing attachment of the QEC to the nacelle. The new brace arrangement affects certain plumbing, wiring, and ducting.

(d) Nose Cowl.

The nose cowl is modified extensively to accommodate the relocation of the forward brace attachment point on each side and to add clearance, mounting, and access for the three added gear box mounts. In addition to the added lower mount supporting structure, an access door is provided in the outer skin and an access opening is provided in the inner skin at the bottom of the nose cowl. In addition to the revised structure at the brace attachment point, an access door is provided forward of this point. The existing sheet metal shelf across the neck of the nose cowl between the air intake scoop and the gear box is replaced by a forged shelf to which the two added upper mounts are attached.

(e) Top Cowl Panel.

The top cowl panel is modified primarily to permit this panel to be removable, providing access to and removal of the engine oil tank. The existing panel is not removable, since the oil tank below the panel was removable through the side cowl opening with the rear engine mount attached to the rear web of the top cowl panel. However, the location of the upper half of the "V" brace now precludes tank removal from the side. The top cowl panel is made removable by attaching the top rear mount to a new QEC rear beam. The shortened panel is fastened to this separate beam, with the ends of the beam attached to the two upper aft brace fittings. A ground handling support is required to stabilize the rear mount when the top cowl panel is removed, since the upper QEC longerons and side cowl panels are not in place. Other changes to the top cowl panel include stiffened longerons, strengthened side cowl panel hinge supports, strengthened oil tank frames, and additional screw attachments to the nose cowl panel.

(f) Side Cowl Panels.

The two side cowl panels are modified to provide clearance between the panels and the "V" braces and to relocate panel mounted components mating with components relocated because of brace interference. The air starter exhaust, provided on airplanes containing the integral start system, is relocated because of brace interference. The lower aft latch and support rod are also relocated because of brace interference. The lower

aft latch now attaches to the lower aft brace fittings instead of to the bottom cowl panel. Both existing lower latches are replaced and panel structure is stiffened to provide greater panel retention under air loads.

(g) Bottom Cowl Panel.

The bottom cowl panel is modified in the aft canted bulkhead and cowl latch attaching areas. The bulkhead is modified to give increased stiffness at the "tie bar" joint. The existing forged aluminum fitting on the upper aft corner on the left side of the panel is replaced by a forged steel fitting similar to the existing fitting due to the brace configuration and higher loads on the left side. The right fitting is unaffected. Removable skin tabs at both corner fittings are provided to gain access to these fittings. The forward latch attachment fittings are revised to accommodate the changed forward lower latches on the side cowl panels. The aft latch attachment fittings are removed from the bottom cowl panel since the aft lower latches on the side cowl panels now attach to the lower aft brace fittings.

(h) Miscellaneous QEC Changes.

Various engine-mounted components are relocated because of brace interference. These components include the EDC (engine-driven compressor) inlet duct, EDC surge valve and electrical connector, starter inlet duct, and the combustor plug, instrument box, and starter exhaust duct on airplanes containing the

integral starting system. The modified EDC's and unmodified EDC's are not interchangeable and are not readily convertible.

(3) Nacelle (See Figure 7)

A few modifications are common to inboard and outboard nacelles. However, most of the nacelle modifications are made in the outboard nacelles only.

(a) Fittings.

Four new machined forged steel fittings, two at the forward ends of the left and right lower longerons and two at the aft ends of the left and right lower diagonal longerons are provided in the outboard nacelles only.

(b) Longerons.

The left upper diagonal, left and right lower diagonal, and upper aft longerons in the outboard nacelles and the lower aft longerons in the inboard and outboard nacelles are modified. The left upper diagonal longeron in the outboard nacelles is stiffened by an added member. The lower diagonal longerons in the outboard nacelles are completely new. The upper aft longerons in the outboard nacelles are stiffened from the firewall to the region of the wing rear beam by the addition of one external and two internal straps. The lower aft longerons in the inboard and outboard nacelles are changed by an increase in the size of the splice angles in the region of the wing front beam. The forward ends of the lower aft longerons in the outboard nacelles only are changed to accommodate new fittings.

(c) Miscellaneous Nacelle Changes.

The side structure of the outboard nacelles is changed between the firewall and wing front beam by an added skin scab section, a skin section of increased thickness, and by strengthened skate angle splices, and the side structure between the tail-pipe cover and the center of the upper wing is modified by three added vertical stiffeners. The side structure of the inboard nacelles will incorporate more angles. The frame between the lower diagonal longerons at the center of the wedge section of the inboard and outboard nacelles is completely new. Two horizontal shelves are added to the left side of all nacelles in the wedge section forward of the firewall to support the added side rear engine mount. The firewall in all nacelles is stiffened by doublers added to some vertical members and webs. The bulkhead at nacelle station -0.49 between the upper aft longerons in the region of the wing front beam in the outboard nacelles is strengthened by added angles to the inner cap and larger attachments to longerons. The frames are cut and spliced on both sides of the inboard nacelles at nacelle station 9.50 to permit nacelle removal without cutting wires. The terminal bulkhead at nacelle station 35.81 at the lower rear of the outboard nacelles is strengthened by added angles. Various other minor changes are made to the nacelle structure.

NOTE

ENGINE - MOUNTED COMPONENT
CHANGES DUE TO BRACE INTERFERENCE:

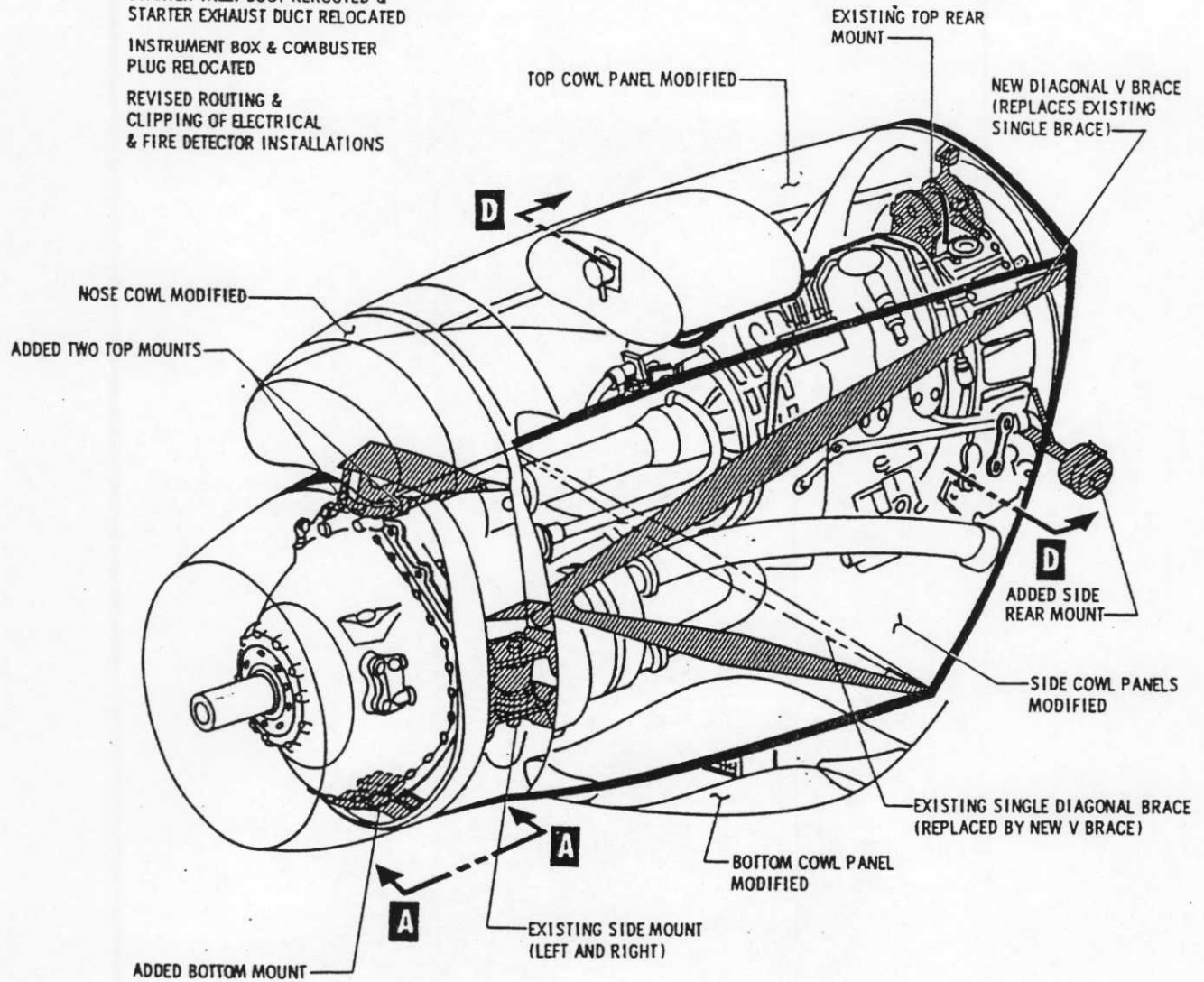
EDC SURGE RELIEF VALVE
ROTATED & INLET DUCT
CONTOURS REVISED

OIL TRANSMITTER BRACKET RELOCATED

STARTER INLET DUCT REROUTED &
STARTER EXHAUST DUCT RELOCATED

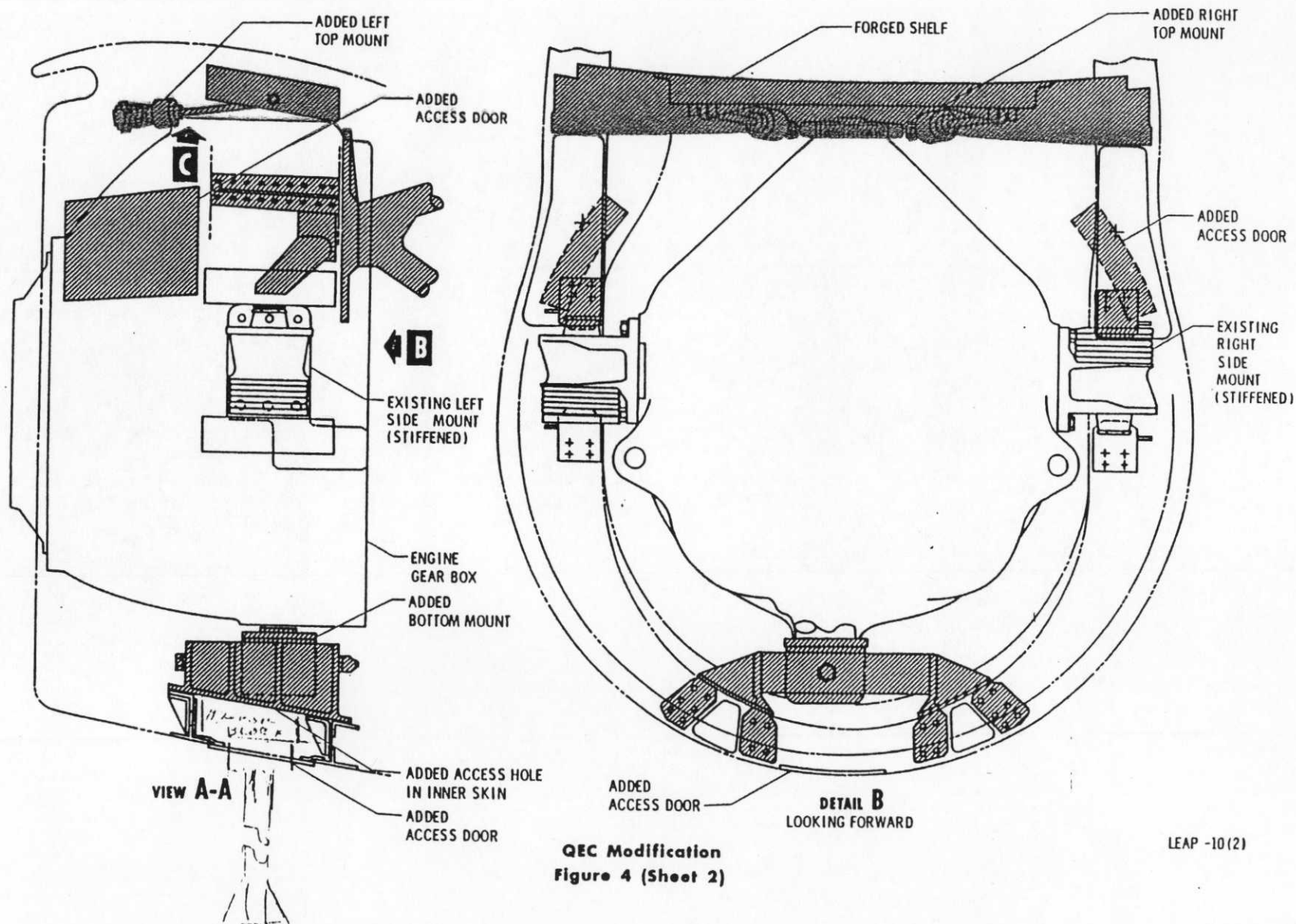
INSTRUMENT BOX & COMBUSTER
PLUG RELOCATED

REVISED ROUTING &
CLIPPING OF ELECTRICAL
& FIRE DETECTOR INSTALLATIONS

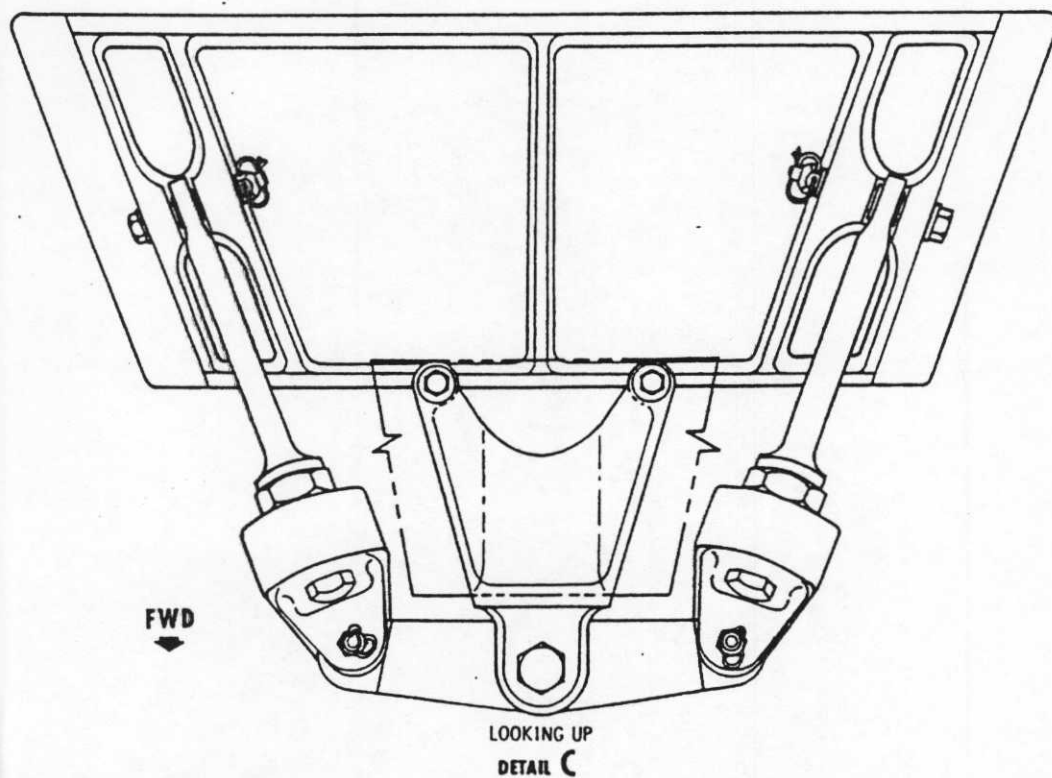
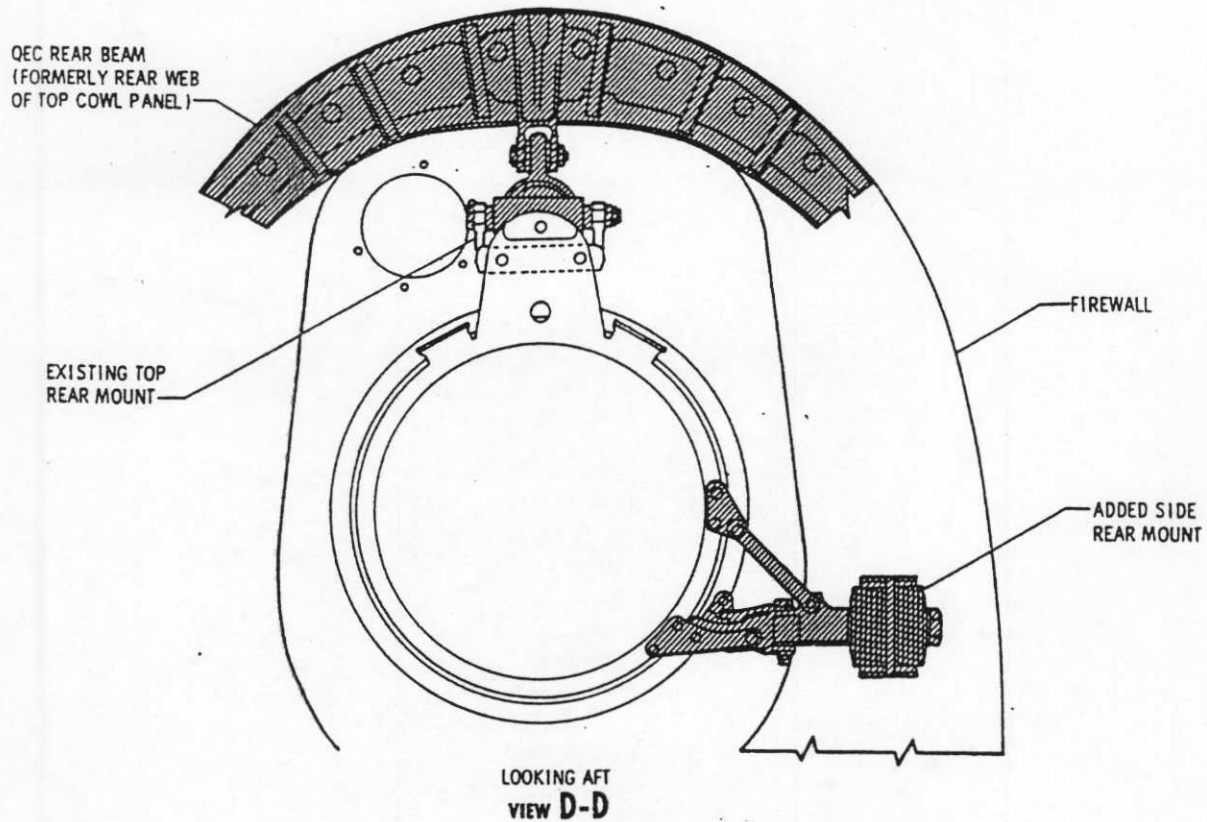


LEAP -10(1)

QEC Modification
Figure 4 (Sheet 1)

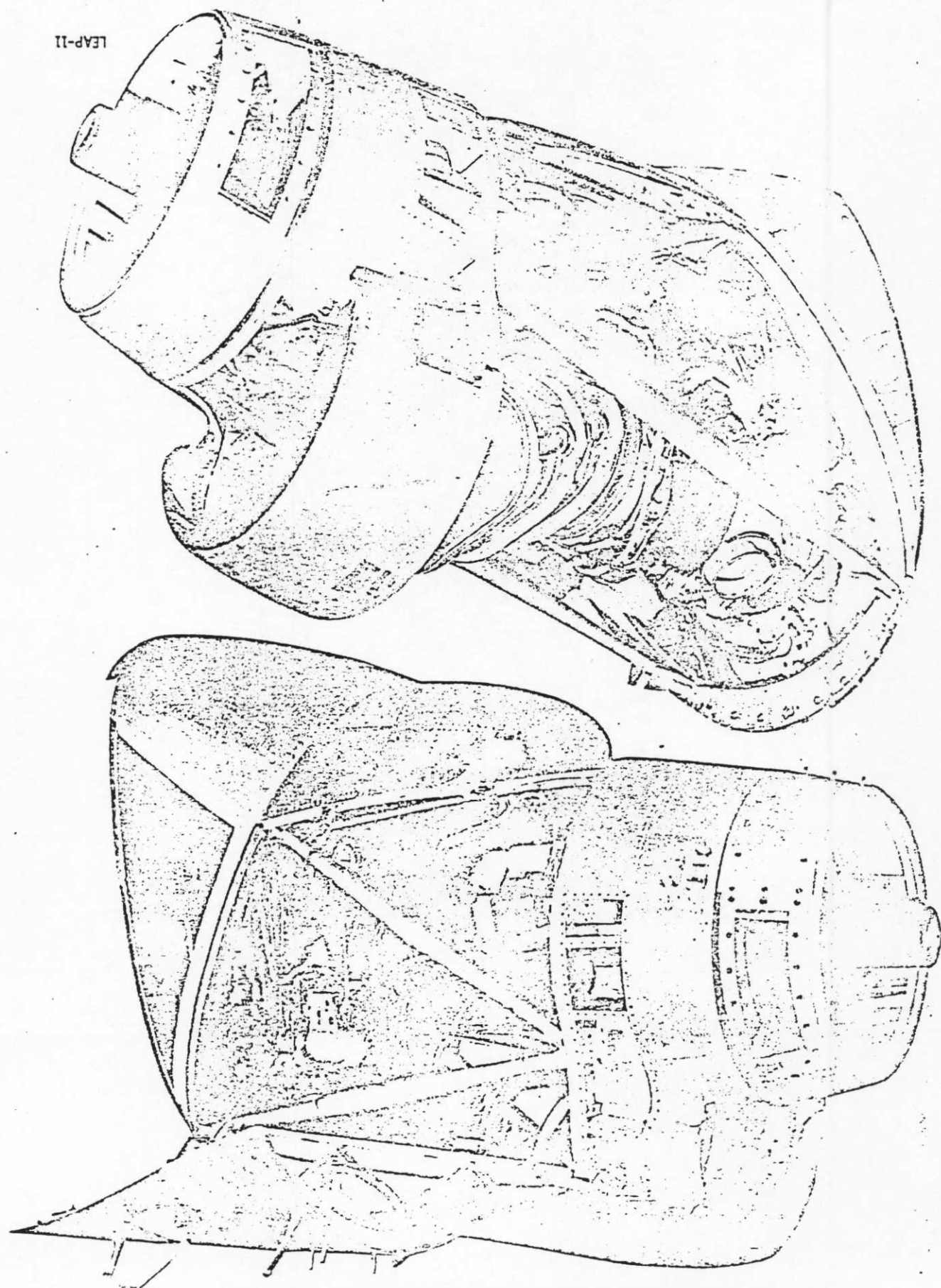


QEC Modification
 Figure 4 (Sheet 2)



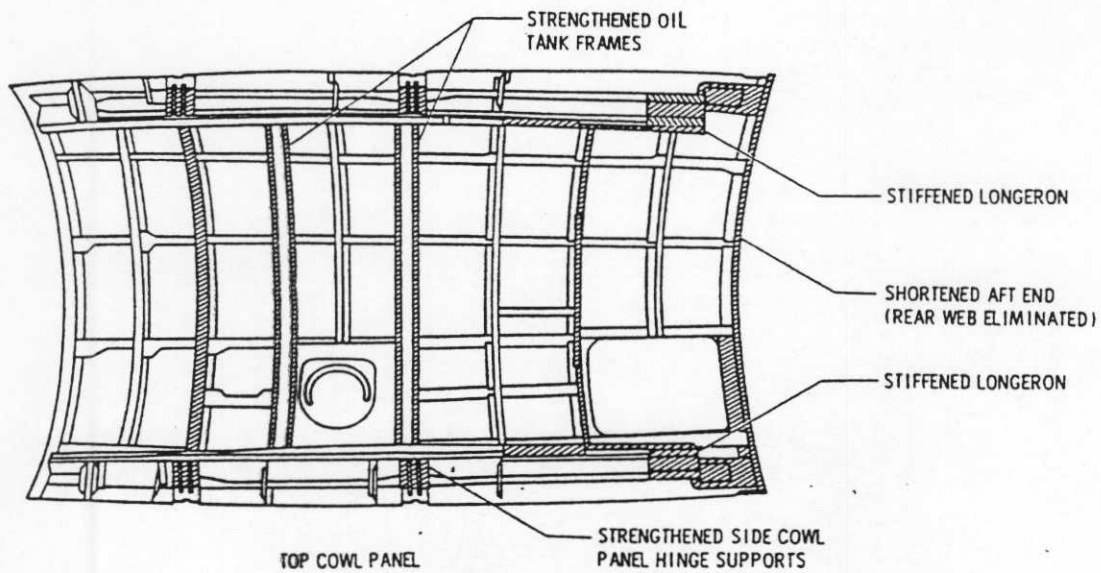
QEC Modification
Figure 4 (Sheet 3)

LEAP-10(3)

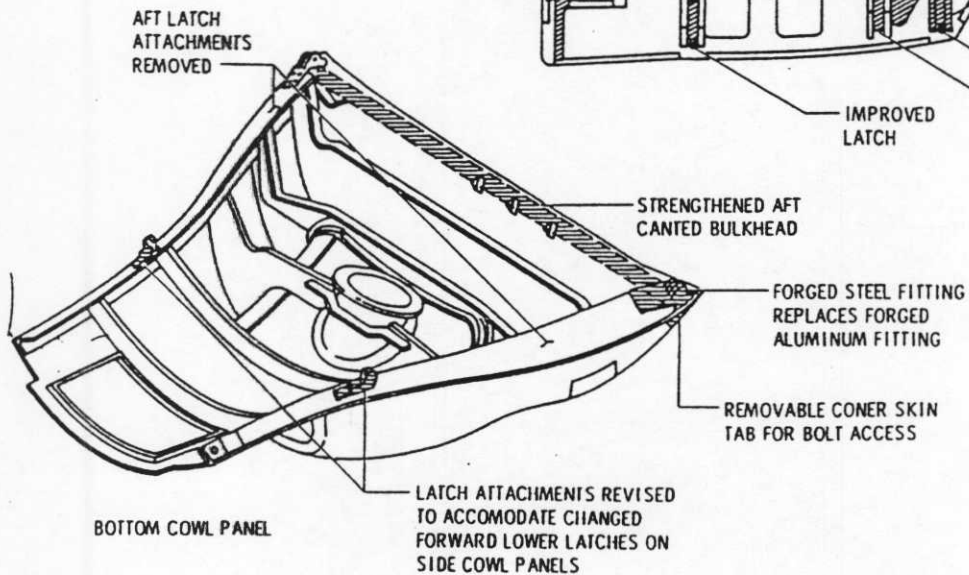
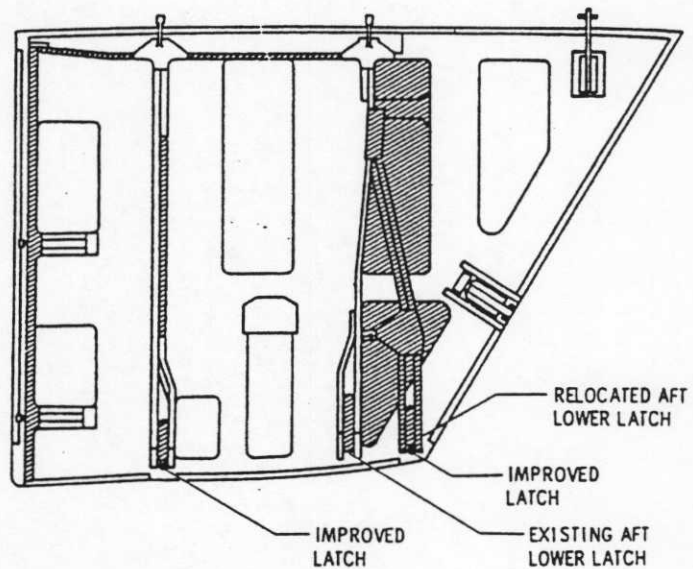


Modified QEC (Mock-up)

Figure 5

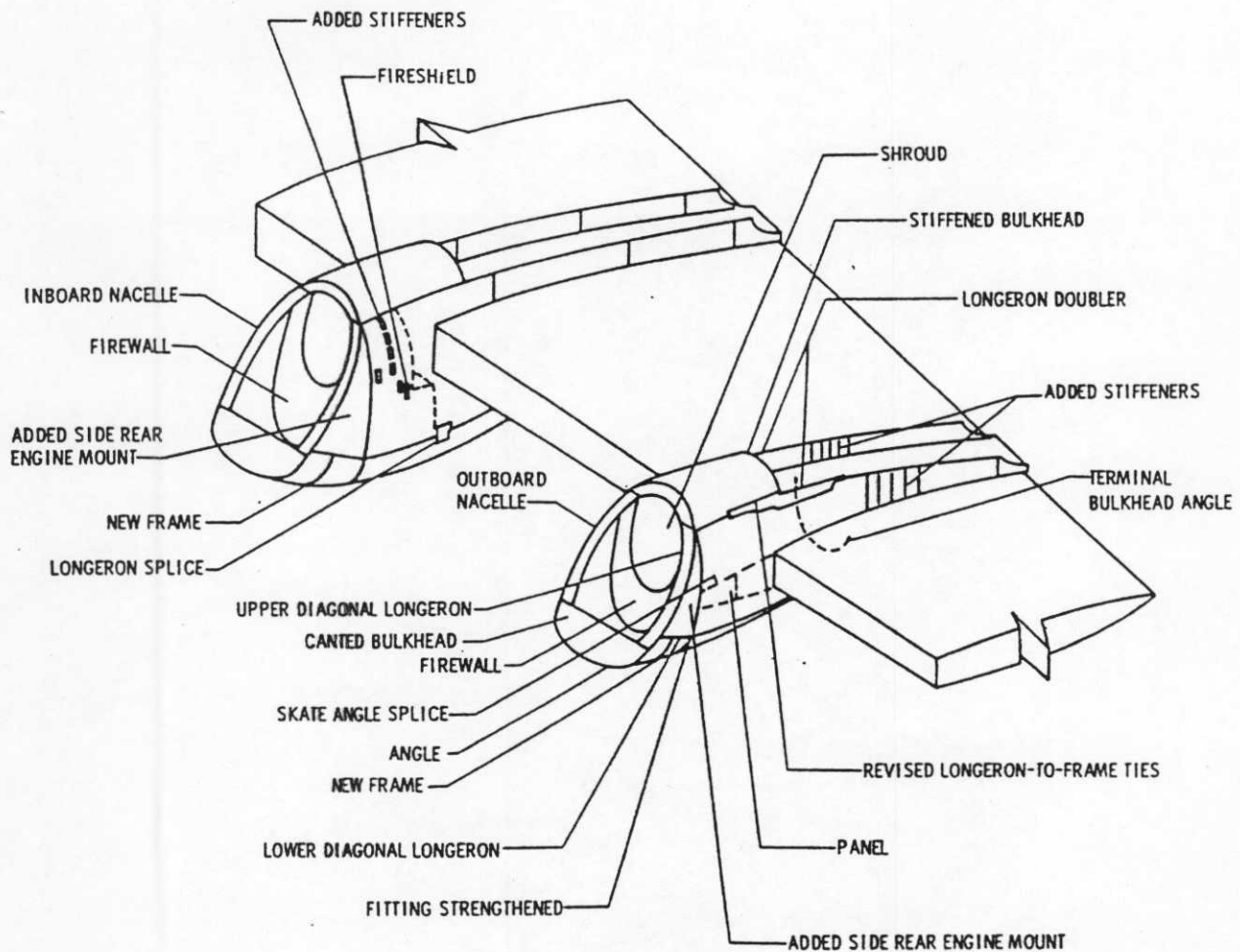


SIDE COWL PANEL



LEAP-12

QEC Cowl Modification
Figure 6



Nacelle Modification
Figure 7